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Low cost solution for strategic air mobility line-tasking problem implemented in the Decision Scheduling System (DSS)

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Abstract

This technichal note provide preliminary advice and evaluation regarding the Decision Scheduling System (DSS). It also presents alternative approaches that can be implemented in DSS to solve the Air mobility line-tasking problem (LTP).

Résumé

Cette note technique présente une recommandation et une évaluation préliminaire du Decision Scheduling System (DSS). Elle présente aussi d'autres approches qui pourraient être implantées dans DSS pour la résolution du problème d'assignation des lignes aériennes.

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Executive summary

The Decision Scheduling System (DSS) has been developed by the GERAD team under a research and development program. The DSS's aim is to solve the airline assignment problem designated as the Air mobility Line Tasking Problem (LTP). Moreover, to be able to solve the LTP problem, the DSS required the Gencol software commercialized by the AdOpt firm. But, the licence cost of the software make the deployment of the DSS too expensive. A study has been undertaken by RDDC Valcartier to evaluate on one hand the DSS and to present on the other hand alternative approaches that can be implemented in DSS to solve the Air mobility LTP.

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1. Introduction

The main objectives of this report can be summarized as follows:

- Provide advice and evaluation regarding the Decision Scheduling System (DSS).

- Present alternative approaches that can be implemented in DSS to solve the Air mobility line-tasking problem (LTP).

Developed by GERAD (Groupe d'Études et de Recherche en Analyse des Décisions) under a DND/NSERC project in which DRDC Valcartier has been involved, the DSS is a prototype system designed to solve the Air Mobility line-tasking problem. The latter consists in selecting airlift requests and construct strategic airlift missions to be achieved over a specific time horizon, generating a monthly or a yearly airlift programme (MAP or YAP). A MAP or a YAP can be seen as a forecast of how missions will be carried out in a given month or a year.

The remainder of this document is organized as follows. The next chapter introduces the line-tasking problem to provide a better comprehension of what follows. Chapter 3 provides a background pertaining to the study undertaken at DRDC Valcartier. Drawbacks and limitations associated with DSS and GENCOL are identified and discussed in Chapter 4. Chapter 5 includes a description of alternative approaches offering the ability to solve the LTP. Recommendations are proposed in Chapter 6. Conclusions are given in the final Chapter.

2. The Air Mobility line-tasking problem

For a given month, 1CAD planners produce a forecast of missions that will be carried out to support a set of requests. The resulting forecast is indeed based on real mission requests, historical data, and operations forecasts. A mission can be considered as an itinerary of a specific aircraft to cover one or more requests.

There are at least two kinds of requests that a planner needs to consider:

1. Strategic airlift requests representing missions to airlift a number of passengers and/or amount of freight from one airfield to another. These requests are well defined in terms of itinerary, time and loading quantities.

2. "Generic requests" mainly dedicated to training tasks (TAL) or Air-to-Air Refuelling (AAR) support. They are less precise in their definition than the airlift requests. It is up to the planner to complete the generic request properties (itinerary, time…) during his/her job.

Normally, the requests for airlift resources exceed capabilities. One of the planner's job is to decide which requests will be supported and by which missions. For this, he\she will first assign a priority to each request according to the existing priorities rules, and then he\she will solve the problem formulated as follows:

> Given a set of prioritized requests, build a set of valid missions in order to maximize the number of supported requests while taking into account the request priorities and minimize the operational costs.

Naturally, the results depend on multiple constraints such as:

- The number of serviceable transport aircraft. The planner assumes that this number is known for each aircraft type at each base for a given month.

- The possible ground activities (briefing, debriefing, stop) that could take place in a feasible mission.

The missions that the planner produces are assembled in different line tasking. The latter can be seen as the routing of a "virtual" aircraft of a defined type, i.e. the missions belonging to a line tasking can be conducted using aircraft of that type. On a line, the time between the end of a mission and the beginning of the next one must usually be greater or equal to 0 (a typical value is 6h).

The line-tasking problem is solved by DSS in two steps. In the first step, a mission generator, built on NETGEN (software developed by GERAD), is used to generate a subset of feasible paths (missions). This set is then used in the second step to find the optimal solution using GENCOL column generator.

3. Background

DSS currently uses GENCOL optimizer, a tool commercialized by AdOpt Technology Company based in Montreal. The licence cost of the GENCOL optimizer and software maintenance makes the deployment of the DSS very expensive for the Air Force given the high cost of Gencol. A comprehensive study has been undertaken at the DRDC Valcartier to achieve a set of objectives:

1. Examine the Canadian military airlift problem.

2. Identify some feasible problem solving techniques to tackle the line-tasking problem.

3. Compare solutions resulting from these techniques with those obtained using the current DSS version.

4. Investigate and identify limitations associated with the current DSS version.

5. Develop approaches to provide the ability to integrate contingency plans into DSS.

The present document can be seen as a summary of the work progress related to the above-mentioned study. It summarizes partial conclusions deduced for the study in progress. These conclusions are basically related to the first three objectives. More information about objectives 4 and 5 can be found respectively in [4] and [5]

The air mobility line-tasking problem and the DSS user-interface were described with a set of documents (principally two reports) written by the GERAD team. The first report [1] describes, on the one hand, the different operations conducted by the Canadian Air Force Mobility and, on the other hand, the line-tasking problem mathematical model [1]. The second report [2] is devoted to describing the user-interface to the DSS optimization software.

We recognize the high quality of the above-mentioned reports and the tremendous work achieved to obtain the results. However, many difficulties have been met in reading the above-mentioned documents [4]. The Air mobility line-tasking problem model and its related variables were not thoroughly explained and therefore difficult to understand. Also the mathematical model proposed in the first above-mentioned document was incomplete. The set-partitioning model (master problem) was presented in document [1]. However, the sub-problems were not presented in any document. Information pertaining to the resolution and the processing of the whole model were not also presented in both reports [1, 2]. Consequently, an information request has been submitted to the GERAD team in order to ease the analysis of the DSS documentation and improve the understanding of the LTP modeling.

A meeting with the GERAD team members has been organized at DRDC Valcartier on April 17, 2003 in order to clarify needed information. Following this meeting, it was concluded that a new appending document must be produced to complement the two other reports. This document must address the following points: i) clarifications regarding the LTP and its

mathematical model, ii) details about the mission generator module, iii) the GENCOL data input file related to the August 96 scenario[1].

In this respect, a draft clarification document [3] has already been produced. The document represents only a preliminary version. On the other hand, the GENCOL data input file related to the August 96 scenario has also been received by the DRDC Valcartier on June 10, 2003. The delay to submit the required documents hampered the good course of this study.

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[1] The numerical tests were based on this scenario.

4. Some DSS-GENCOL limitations

DSS is an open-loop decision support system incorporating GENCOL as an optimizer. GENCOL uses Cplex to conduct the optimization process. DSS uses three components to solve the Strategic Airlift problem: NETGEN, GENCOL, and Cplex.

GENCOL is based on the column generation approach, which in operational research is referred to as a problem decomposition method. The column generation approach is used to solve large-scale problems such as those related to the airline industry: aircraft routing and scheduling. The typical weekly schedule of a large civilian airline contains thousands of flight legs (more than 3000 flight legs for Air Canada), several hundreds aircraft, and five to ten aircraft types. The military Air Mobility line-tasking problem targeted to be solved by DSS is different from those mentioned above. For instance, the August 96 scenario deals with 13 aircraft and 3 bases (Trenton, Winnipeg, and Greenwood). The military Air Mobility LTP can be considered as a medium-size problem. However, the time windows on leg make the problem difficult to solve. We believe that the LTP can be solved without using decomposition approach mainly due to several factors:

- The size of the problem

- Assumptions related to the mission generator that led to problem simplifications as well as additionnal simplifications hypothesis, despite computational exponentiel complexity of the resulting problem.

The GENCOL development has been an ongoing process for more than two decades and has also been improved during the last few years. Based on the column generation approach, the GENCOL engine was considered perhaps as the most powerful optimizer in the late eighties. However, a number of available commercial software offers now the possibility to solve large-size problems. On the other hand, Cplex[2] provides the ability to use the decomposition approach (column generation). These tools are very accessible and cheap in comparison to the GENCOL solver.

Another problem associated with the deployment of the DSS-GENCOL lies in the need to acquire the required licences for the Air Force. Note that the cost of three licences and software maintenance is about one million Canadian dollars.

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[2] Developed by ILOG Company.

5. Alternative approaches

At least, two approaches or techniques to solving the line-tasking problem (a variant of vehicle scheduling problem) have indeed been identified as potential alternatives to the approach incorporated into the DSS tool.

- The first approach consists in solving via Cplex the problem related to the subset of paths generated by NETGEN. The GENCOL is not used in this case and the problem is solved without using the decomposition approach. Non-linear constraints are transformed into linear constraints. This approach consists in solving the original LTP as a whole mixed integer problem. It is worth noting that this proposed technique is very easy to implement. The resulting solution of the considered problem related to the subset of paths is optimal. Solving the LTP in such fashion requires just the software NETGEN and Cplex. NETGEN is thus used to generate a subset of feasible missions, while Cplex can be implemented to carry out the optimization process.

- The second approach amounts to using the Cplex software column generator to solve the LTP problem. Indeed, the Cplex column generator package requires the use of the Concert Technology software developed by ILOG. Note that the Concert technology software is a component of the Cplex package. It is important to mention that this solution is not very effective and requires considerable run time. However, it can be improved by implementing the dynamic programming (DP) algorithm to model and solve the sub-problems as shortest path problem with resource constraints. This second proposed approach requires considerable programming effort. It must be implemented through NETGEN, the Cplex software and the development of a program (based on DP) to solve the sub-problems.

Other solution approaches could use meta-heuristics (e.g. evolutionary algorithms). In this study, these approaches were not explored.

6. Preliminary tests and recommendations

Preliminary tests were performed to try to solve benchmark problems using GENCOL, MIP Cplex solver and Cplex Column Generator. The three approaches proposed above produced the same results with approximately the same performance (runtime).

Other tests were performed on the August 96 scenario using the first approach. The same problem solved by GENCOL (input GENCOL Data File) was used to build the input data file for the Cplex solver. Cplex easily solved the problem; the total running time was about 30 seconds. The problem solved consists in minimizing the total flown time by all aircraft and covering the maximum prioritized requests. The resulting solution was 68 746 minutes as total flight time, while the GENCOL solution is 68 933 minutes as total flight time. The difference between the two solutions is less than 0.3%. It should be mentioned that our investigation was limited to only one scenario, which represents a limit of the current study.

This study illustrates that the line-tasking problem can be solved without using the GENCOL software. The solution technique used is a low-cost solution when compared with the GENCOL version. We recommend strongly the Canadian Air Force to investigate replacing the GENCOL solver in the actual DSS version assuming the model unchanged. A cost-effectiveness analysis should be carried out to evaluate the effort required to upgrade DSS. Other technical solutions are also under investigation.

7. Conclusion

This document is a preliminary executive report of a study designed to provide advice to the Canadian Air Force regarding the deployment of the Decision Scheduling System (DSS) dedicated to address the Air Mobility Line-Tasking problem. This study has been limited to compare three optimization approaches: GENCOL, MIP Cplex Solver and Cplex Column Generator. DSS requires the GENCOL optimization engine. The licence cost of GENCOL software makes the deployment of the DSS very expensive for the AF. The results of the preliminary tests performed using an alternative approach show that the LTP can be solved with alternative approaches (exact and/or heuristic methods). Lower cost solutions could be considered to solve the LTP problem using NETGEN and Cplex software.

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